the length of the pipe by this velocity to obtain the time of flow through the pipe.

Sample Design Problem

The following example problem is shown to illustrate the design steps, the use of the various charts and nomographs, and the preparation of the Storm Drainage Design Sheets.

The example involves a roadway that crosses a small valley at Station 205+95 with -1.30% and +1.83% grades resulting in a sump at the center of a 200-foot vertical curve. As Figure 6-1 shows, grated inlets catch the runoff in curbed gutters at Station 204+00 and at the gutter sumps at Station 205+78.1. In addition, sodded ditches intercept the runoff from the drainage area to the south of the highway, and these ditch runoffs are collected by grated inlets in the ditch at 204+00 and at the low sag at 205+95. The runoff from the inlets on the south edge of the highway is then conveyed under the highway where the north-side inlets are picked up and the accumulated runoff is discharged into a small natural watercourse.

The traversed area is suburban in character, and its zoning indicates residential apartments assumed to result in 70% imperviousness.

The rational method is to be used and the runoff coefficients for pervious and impervious areas are assumed to be 0.30 and 0.95, respectively. The system will be designed for a 10-year storm.

Design Steps

1-4. The runoff coefficients and acreage of the tributary areas for each inlet are summarized in Figure 6-3.

5. The storm frequency to be used in design is 10 years.

6. The initial time of concentration is determined for inlet 1 from the overland flowtime nomograph (Figure 6-12). For this case the length of the strip (i.e., the distance between the inlet and the point farthest from it within its tributary area) is 500'. The ground is an average grass surface, and the slope of the ground is 1%. For these conditions, Tc = 26.5 min. The rainfall intensity for this Tc in Sussex County (see Figure 6-15) is 3.85 in/hr.

7. The selected tentative pipe sizes and slopes are shown on the location and profile sheets as well as the storm drainage design sheet.

8. Figure 6-3 is the completed Storm Drainage Design sheet for this example.

9. Figure 6-2 shows the profile for the proposed system.

10. <u>Computing the Hydraulic Gradient</u>

The losses in each structure and reach are computed as follows and documented as shown in Figure 6-4:

<u>INLET 1</u>

A. Velocity diagram: $V_R \dashrightarrow ① \xrightarrow[V_2]{} ②$

V_R = 0 (due to overland flow)
V_2 = 7.99 fps exit velocity

B. Flow diagram: $Q_R \dashrightarrow ① \xrightarrow[Q^2]{} ②$

$Q_R = Q_2$ = 7.53 cfs Initial system inlet

C. Head loss in structures (Figures 6-21 and 6-22)

1. Entrance head loss from V_1 to V_2

From Curve "A" H_L = <u>0.35 ft.</u>

2. Head loss due to change in velocity from V_R to V_2

From Curve "B" $H_{L2} - H_{LR}$ = <u>0.99 ft.</u>

3. Head loss due to bends:

$H_L = \underline{0}$

4. Head loss due to secondary flows:

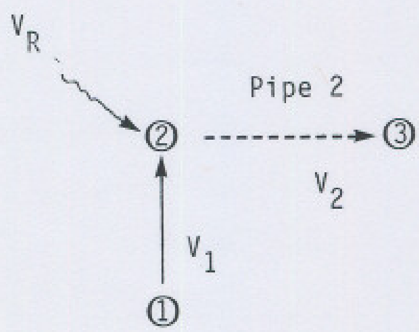
$H_L = \underline{0}$

Total H_L = <u>1.34 ft.</u>

<u>INLET 2</u>

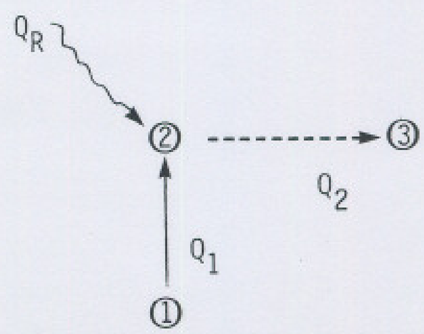
A. Velocity diagram:

$V_R = 0$
$V_1 = 7.99$ fps
$V_2 = 7.53$ fps



B. Flow diagram:

$Q_R = 1.40$ cfs
$Q_1 = 7.53$ cfs
$Q_2 = Q_R + Q_1 = 8.93$ cfs



C. Head loss in structures:

1. Entrance head loss -- using largest entrance velocity (V_1).

   From Curve "A" H_L = <u>0.35 ft.</u>

2. Head loss due to change in velocity from V_1 to V_2.

   From Curve "B" $H_{L2} - H_{L1} = 0.90 - 0.99 =$ <u>-0.9 ft.</u>

3. Head loss due to bends (90^o bend)

   From Curve "C" using largest existing velocity

   $H_L = 0.19 \times 2.0 =$ <u>0.38 ft.</u>

4. Head loss due to secondary flows. (Figure 6-22)

   From Curve "D" (Q_R = secondary flow, Q_1 = upstream flow)

   $$\frac{Q_R}{Q_1} = \frac{1.40 \text{ cfs}}{7.53 \text{ cfs}} = 0.19 = 19\%$$

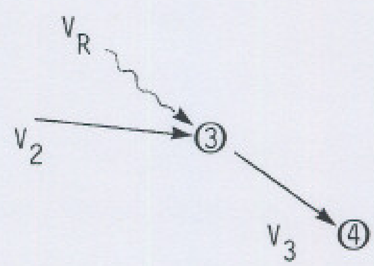
   Using $V_1 = 7.99$ fps H_L = <u>0.17 ft.</u>

   Total $H_L = 0.81$ ft.

<u>INLET 3</u>

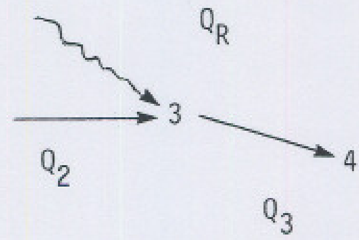
A. Velocity diagram:

$V_R = 0$
$V_2 = 7.53$ fps
$V_3 = 9.25$ fps



B. Flow diagram:

Q_R = 1.71 cfs
Q_2 = 8.93 cfs
$Q_3 = Q_R + Q_2$ = 10.64 cfs



C. Head loss in structures:

1. Entrance head loss -- using largest entrance velocity (V_2).

   H_L = <u>0.35 ft.</u>

2. Head loss due to change in velocity from V_2 to V_3.

   From Curve "B" $H_{L3} - H_{L2} = 1.31 - 0.91 =$ <u>0.40 ft.</u>

3. Head loss due to bends (17^o bend)

   From Curve "C" using largest existing velocity (V_3)

   $H_L = 0.25 \times 1/3(.25) =$ <u>0.17 ft.</u>

4. Head loss due to secondary flows

   From Curve "D" (Q_R = 1.71 cfs secondary flow, Q_2 = 8.93 cfs upstream flow)

   $$\frac{Q_R}{Q_2} = \frac{1.71 \text{ cfs}}{8.93 \text{ cfs}} = 0.19 = 19\%$$

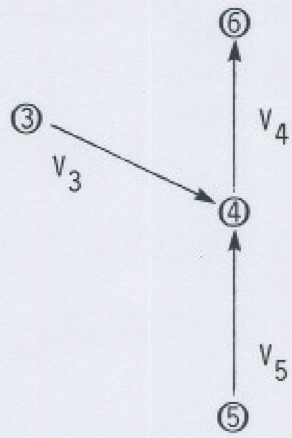
   Using V_2 = 7.53 fps H_L = <u>0.15 ft.</u>

   Total H_L = 1.07 fts.

INLET 4

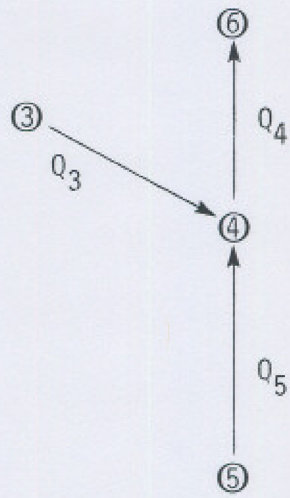
A. Velocity diagram:

V_3 = 9.25 fs
V_4 = 6.50 fs
V_5 = 5.08 fs



B. Flow diagram:

Q_3 = 10.64 cfs
Q4 = Q_3 + Q_5 = 13.04 cfs
Q5 = 2.40 cfs



C. Head loss in structures:

1. Entrance head loss -- using largest entrance velocity (V_3).

   From Curve "A" H_L = 0.43 ft.

2. Head loss due to change in velocity from V_3 to V_4.

   From Curve "B" $H_{L4} - H_{L3}$ = .67 - 1.36 = 0.69 ft.

3. Head loss due to bends (90^o bend)

   From Curve "C" using largest existing velocity
   H_L = 0.25 x 2.0 = 0.50 ft.

4. Head loss due to secondary flows

From Curve "D" (Q_5 = 2.40 cfs secondary flow, Q_1 = 9.25 cfs upstream flow)

$$\frac{Q_5}{Q_1} = \frac{2.40 \text{ cfs}}{9.25 \text{ cfs}} = 0.26 = 26\%$$

Using V_3 = 9.25 cfs H_L = <u>0.33 ft.</u>

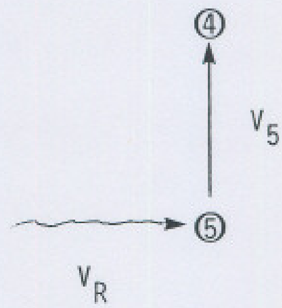
Total H_L = <u>0.57 ft.</u>

<u>INLET 5</u>

A. Velocity diagram:

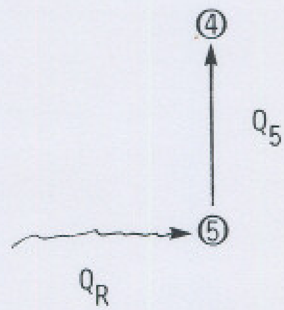
$V_R = 0$

$V_5 = 5.08$ fs



B. Flow diagram:

$Q_R = Q_5 = 2.40$ cfs



C. Head loss in structures:

1. Entrance head loss -- using largest entrance velocity (V_5).

H_L = <u>0.15 ft.</u>

2. Head loss due to change in velocity from V_R to V_5.

From Curve "B" $H_{L5} - H_{L6} = (0.40 - 0) =$ <u>0.40 ft.</u>

3. Head loss due to bends (0 bend)

   $H_L = 0$

4. Head loss due to secondary flows
   No secondary

   $H_L = 0$

   Total $H_L = 0.55$ ft.

INLET 7

A. Velocity diagram:

   $V_R = 0$
   $V_7 = 4.14$ cfs

$$V_R \longrightarrow 7 \xrightarrow[V_7]{} 6$$

B. Flow diagram:

   $Q_R = Q_7 = 1.86$ cfs

$$Q_R \longrightarrow 7 \xrightarrow[Q_7]{} 6$$

C. Head loss in structures:

1. Entrance head loss -- using largest entrance velocity (V_7).

   From Curve "A" H_L = <u>0.11 ft.</u>

2. Head loss due to change in velocity from V_R to V_7.

   From Curve "B" $H_{L7} - H_{LR} = (0.27 - 0) = \underline{0.27 \text{ ft.}}$

3. Head loss due to bends (0 bend)

   $H_L = 0$

4. Head loss due to secondary flows

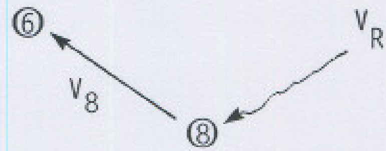
No secondary

$H_L = 0$

Total $H_L = 0.38$ ft.

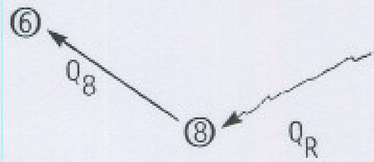
INLET 8

A. Velocity diagram:



$V_R = 0$
$V_8 = 5.20$ cfs

B. Flow diagram:



$Q_R = Q_8 = 1.68$

C. Head loss in structures:

1. Entrance head loss -- using largest entrance velocity (V_8).

   From Curve "A" H_L = 0.16 ft.

2. Head loss due to change in velocity from V_8 to V_R.

   From Curve "B" $H_{L8} - H_{LR} = (0.43 - 0) =$ 0.43 ft.

3. Head loss due to bends (0 bend)

   $H_L = 0$

4. Head loss due to secondary flows
   No secondary

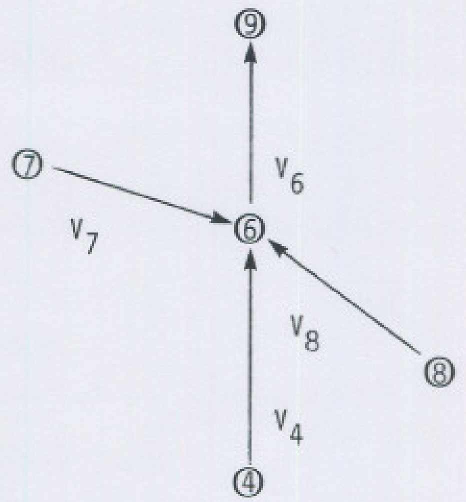
   $H_L = 0$

   Total H_L = <u>0.59 ft.</u>

INLET 6

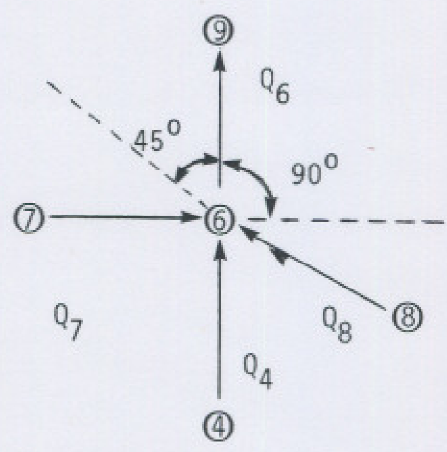
A. Velocity diagram:

V_4 = 6.50 fps
V_6 = 6.10 fps
V_7 = 4.14 fps
V_8 = 5.20 fps



B. Flow diagram:

Q4 = 13.04 cfs
Q6 = 16.58 cfs
Q7 = 1.86 cfs
Q8 = 1.68 cfs



C. Head loss in structures:

1. Entrance head loss -- using largest entrance velocity (V_4).

   From Curve "A" H_L = <u>0.23 ft.</u>